The Gamow-Teller Beta Decay of $^{100}$Cd *

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Neutron-deficient isotopes of cadmium were produced in the $p(600\text{ MeV})+^{nat}\text{Sn}$ spallation reaction. The ISOLDE facility provided mass-separated beams of these isotopes. The production yield was $10^3$ to $10^4$ atoms/s for $^{106}$Cd and roughly two orders of magnitude less for $^{98}$Cd. The properties of the $^{106}$Cd $\rightarrow$ $^{106}$Ag decay were studied in detail by X-ray, $\gamma$-ray and conversion electron spectroscopy. Forty nine $\gamma$-transitions were assigned to this decay, and all but five of them were placed in the decay scheme. The half-life was determined to be $49.1 \pm 0.5$ s. The $Q_{\text{EC}}$ value of $3890 \pm 70$ keV was deduced from a comparison of experimental and theoretical $\beta^+/\text{EC} + \beta^+$ probability ratios. Seven $0^+ \rightarrow 1^+$ Gamow-Teller transitions with $\log f_t$ values between 3.5 and 4.9 were identified. The total (summed) strength is about five times smaller than predicted by the shell model for the transformation of a $g_{9/2}$ proton into a $g_{7/2}$ neutron. The quenching of the Gamow-Teller strength and other questions of nuclear structure are discussed for the $^{106}$Cd decay. The properties of $^{98}$Cd are inferred by extrapolation of $^{106}$Cd data, and some preliminary experimental results on $^{98}$Cd decay are presented.

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1. Introduction

The ISOLDE on-line mass separator offers exceptionally good conditions for the investigation of neutron-deficient cadmium isotopes [1-4], which are produced with a high yield and good Z-selectivity. We took advantage of these conditions to study the $^{106}$Cd $\rightarrow$ $^{106}$Ag decay in detail and to obtain preliminary results for $^{98}$Cd. The work is part of our efforts to approach experimentally as close as possible to the very exotic and as yet unobserved nucleus $^{106}$Sn (see Fig. 1). Earlier results obtained at GSI within this programme for $^{96}$Pd and $^{104,108}$Sn are presented in [6-8], respectively.

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Fig. 1. Part of the chart of nuclides showing the position of the light isotopes of cadmium relative to $^{106}$Sn and to the closest stable nuclei (hatched squares). For each of these isotopes the half-life (in seconds) and the production yield (in atoms/s at 1 µA proton beam intensity) at the collector of the ISOLDE facility are given. The limits of particle stability are taken from [5]
The study of nuclei near a doubly magic one is obviously important for testing nuclear models. For the $\beta$-decay of an even-even nucleus close to $^{100}$Sn, with $Z \leq 50$ and $N \geq 50$, the extreme single particle shell model (ESPSM) predicts only one Gamow-Teller ($0^+ \rightarrow 1^+$) transition, which proceeds through the transformation of a $g_{9/2}$ proton into a $g_{7/2}$ neutron. In reality one observes several $0^+ \rightarrow 1^+$ transitions in the $^{100}$Sn region, the strength of each transition being determined by the amplitude of the $[(\pi g_{9/2})^{-1}, v g_{7/2}]$ component of the $1^+$ state wave-function. However, the summed strengths obtained experimentally are several times smaller than the theoretical values given by the shell model. This phenomenon is known as Gamow-Teller (GT) strength quenching ([9] and earlier papers quoted therein). The main goal of our studies is to identify the GT transitions and measure their strength, and hence to make a quantitative estimate of the amount of quenching in the $^{100}$Sn region. The splitting of the GT strength is an interesting problem in itself, and we discuss in Sect. 6 the role of residual interactions in causing the splitting. When summing the GT strength one may ask whether all EC/$\beta$ transitions to low-lying states have been experimentally established. To have confidence that all these states have been observed, one needs an even-even nucleus produced with a high rate, enabling a study of fine details of the decay scheme, and having a large decay energy $Q_{EC}$. With a production rate reaching $10^4$ atoms/s and $Q_{EC}$ close to 4 MeV, $^{100}$Cd fulfills these requirements rather well. Indeed, we were able to obtain comprehensive information on the decay of this nucleus. Seven GT $0^+ \rightarrow 1^+$ transitions are established (while only four such transitions have been observed for $^{96}$Pd and $^{104}$Sn). These data are, we believe, a firm basis for the discussion in Sect.6 of the GT strength features in terms of nuclear models.

Preliminary results obtained for $^{98}$Cd, see Sect. 3, allow us to plan a future experiment on the decay of this $N = 50$ nucleus [10].

2. Experimental Techniques

The $\approx 100$ g/cm$^2$ molten tin target of the ISOLDE II facility [11] was irradiated by a 600 MeV, 2.2 $\mu$A proton beam. Neutron-deficient isotopes of cadmium were produced in the $^{94}$Sn(p, 3pxn) spallation reaction and mass-separated on-line. Selected activities were periodically collected on a tape over a chosen time interval and transported to the counting position. The production yields (as given in Fig. 1) were estimated from the measured intensities of characteristic $\gamma$-radiation. These yields were generally lower than the maximum yields reported by Ravn [4], probably because the target was maintained at a slightly lower temperature.

Our studies of the $^{100}$Cd decay scheme were carried out with the use of three different detector arrangements.

Arrangement I included a high resolution X-ray Ge(i) detector (with FWHM of 500 eV for the 60 keV line of $^{241}$Am), a 20% Ge(i) $\gamma$-detector and a 33% Ge(i) $\gamma$-detector. Singles spectra and $X-\gamma X-\gamma$-time coincidences were recorded. The energy and efficiency calibration of these detectors was carefully performed with standard sources, and by on-line collection of $^{100}$Cd activity, which has lines of precisely known energies and intensities [12]. Additionally, $^{152}$Eu activity implanted into the transport tape during an earlier ISOLDE experiment turned out to be very useful.

Arrangement II consisted of the 20% $\gamma$-detector and a 28% Ge(Li) $\gamma$-detector. The $X-\gamma$-time coincidences were measured for sources positioned inside a sandwich of two 2.5 mm thick copper plates acting as a positron annihilator (see [6] for the description of a similar set-up). The annihilator was essential for the determination of the $Q_{EC}$ value from the EC/$\beta$ ratio (discussed in Sect. 5). To avoid a registration of both annihilation quanta in coincidence, and to minimize the effect of angular correlations, the two detectors were placed at about 125$^\circ$.

In Arrangement III, a mini-orange spectrometer [13] and the 20% detector or the X-ray detector from Arrangement I were installed in 180$^\circ$ geometry to measure singles $e^-$ and $\gamma$ spectra as well as $e^-$ - $\gamma$-time coincidences. In our investigation of $^{100}$Cd decay we used two different mini-orange filters with a high (up to 10%) peak detection efficiency and relatively narrow (0.4 p) transmission characteristics. By applying three different magnet-to-detector distances the two filters were used in the energy range from 50 to 200 keV and 200 to 700 keV. All conversion electron lines were measured with more than one magnet setting in order to minimize calibration errors. Transitions with well-known conversion coefficients served for the efficiency calibration. Activities produced on-line, such as $^{101}$mAg, $^{102}$Cd and $^{77}$mBr contamination were used, as well as a standard $^{152}$Eu source.

The Arrangements I and III were also used in the preliminary studies of the $^{98}$Cd decay.

The new ISOLDE data acquisition system based on a VAX-750 computer and GOOSY software [14]